ANALYSIS OF VEHICLE STABILITY CONTROL (VSC)'S EFFECTIVENESS FROM ACCIDENT DATA

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ABSTRACT

VSC (Vehicle Stability Control) is one of the representative systems developed to help prevent skidding and unstable behavior before they lead to an accident. We have studied the effectiveness of VSC in reducing accidents in Japan.

From analysis of the statistics of traffic accidents, it is estimated that the accident rate (accidents per vehicles in use per year) of vehicles with VSC showed approximately a 35% reduction for single car accidents and a 30% reduction for head-on collisions with other automobiles. For more severe accidents, this result would improve to approximately 50% and 40% reductions. The casualty rate (casualties per vehicles in use per year) of vehicles with VSC showed approximately a 35% reduction for both types of accidents. Analysis showed that VSC may reduce more accidents in higher speed ranges where vehicle dynamics plays a greater part.

However, It is important to say that VSC cannot prevent all accidents or compensate for all driver errors. VSC is not a substitute for safe driving practices, common sense, and the exercise of good judgment by drivers.

INTRODUCTION

Characteristics of Serious Accidents

In Japan, the number of fatalities per year began to decline from its second peak in the early 90s, and has now reached an almost fixed level of around nine-thousand (see Figure 1).

Still, the number of accidents is rising rapidly, and it is considered that it will rise further in the future, as the overall number of motor vehicles in use increases because larger numbers of middle-aged people are keeping their driver's license as they become older, while there are not so many drivers in the older age group at present.

Figure 2 shows an example of results of traffic accident surveys related to vehicle dynamics performance conducted before TOYOTA's first VSC development. When the circumstances of serious accidents are examined, it can be seen that approximately 20% of such accidents are caused by loss-of-control. It is revealed that there is a relatively large number of cases where the vehicle skidded and the driver lost control, resulting in a serious accident. In most cases the driver made an inadequate steering maneuver or miss-judged the changes in road surface conditions incorrectly. Therefore, VSC was developed to be able to help compensate these kinds of miss-operation or miss-judgement.

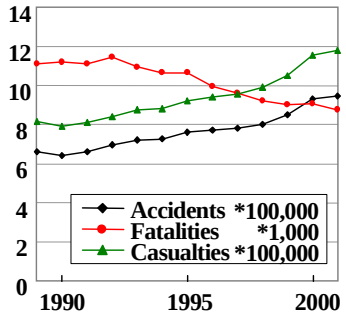


Figure 1. Trend of Traffic Accident Statistics in Japan

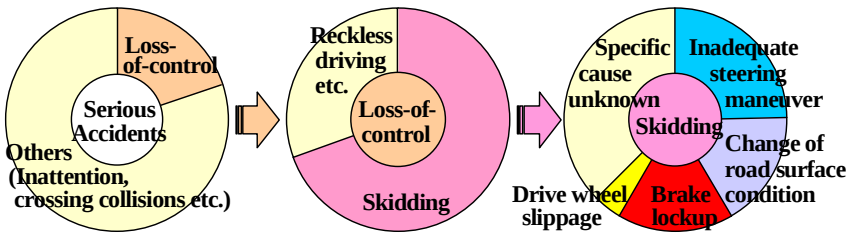


Figure 2. Breakdown of Serious Accidents

Concept and the Function of VSC

To explain the concept of VSC, an analogy will be used referring to Figure 3. In the figure, the ball represents the vehicle's dynamic state and the bowl represents the vehicle's capacity. Loss-of-control can be thought of as when the ball goes over the rim of the bowl.

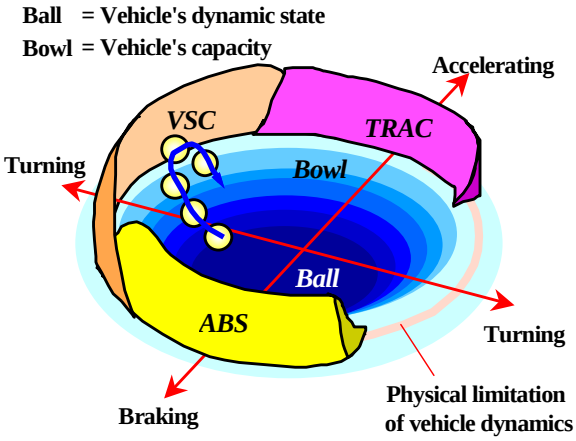
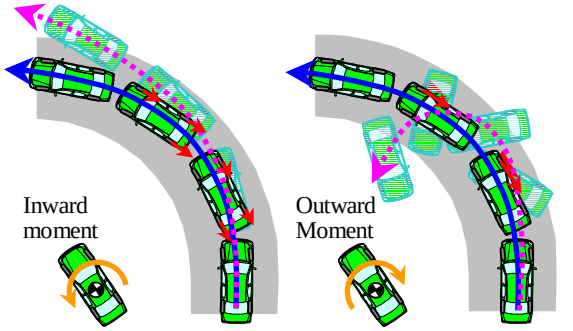


Figure 3. Concept of VSC (Ball in Bowl)

During ordinary driving, the bowl is sufficiently large and deep for the motion of the ball. When the motion of the ball becomes excessive, however, such as when the steering wheel of a vehicle is suddenly turned, or the bowl becomes smaller such as when driving on icy or snowy roads, there is the possibility of the ball going over the rim of the bowl. This is where the vehicle becomes hard to handle.

ABS and TRAC (Traction Control) systems aim to improve control and stability by working to guard the rim of the bowl in terms of braking and accelerating. These systems, however, do not guard the rim of the bowl in terms of turning. This is where VSC comes into play. VSC aims to control vehicle behavior under these types of conditions by assisting the driver. In other words, VSC aims to work together with ABS and TRAC to improve control and stability by guarding the entire area of the longitudinal and lateral motions of the vehicle, as shown on the left side of the bowl in Figure 3.

With VSC control, a deceleration force and an appropriate amount of inward moment are added to help prevent front-wheel-skid and improve course-tracking performance, and outward moment is added to help prevent rear-wheel-skid and improve vehicle posture (see Figure 4).



(a) Prevention of Front-wheel-skidding **(b) Prevention of Rear-wheel-skidding**

Figure 4. Skid Prevention of VSC

Toyota is one of the manufacturers introducing this technology to the market [1,2]. Systems that possess the same function have been developed by many companies under different names such as ESP or VDC [3,4,5], and have been installed in production vehicles.

The next 3 graphs show the characteristics of each type of accidents caused by cars. The accident data used in all graphs in this paper was compiled by The Institute for Traffic Accident Research and Data Analysis (ITARDA; Japan) for the study. ITARDA was founded in 1992 and has been working to analyze the causes of traffic accidents by utilizing the data of all traffic accidents reported by the police that involve casualties, as well as the data gathered through its own in-depth investigations. About 1,000,000 items of the former data, and about 300 items of the latter data have been accumulated per year.

Figure 5 indicates that most of all accidents consisted of rear-end collisions and crossing collisions, but many accidents where severe vehicle damage is caused involve single car accidents and head-on collisions.

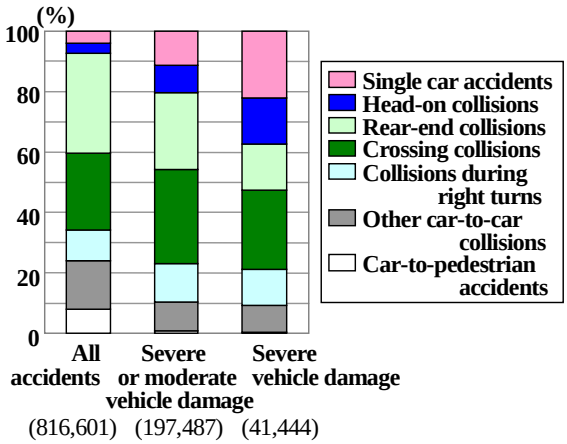


Figure 5. Accidents Caused by Cars by Extent of Vehicle Damage in Japan in 2001

Figure 6 also indicates most casualties were caused by rear-end collisions and crossing collisions, but single car accidents, head-on collisions and car-to-pedestrian accidents yield many fatalities.

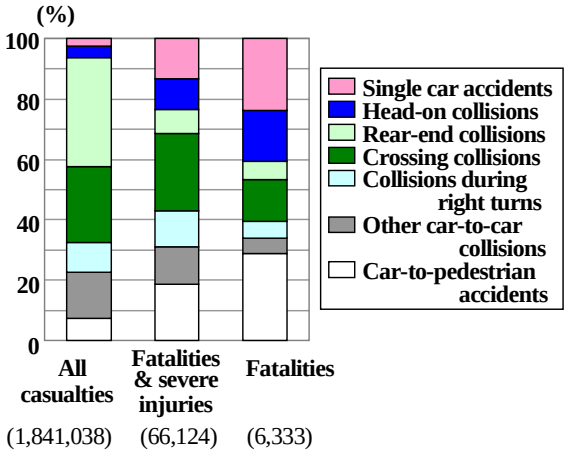


Figure 6. Casualties Caused by Cars by Extent of Injury in Japan in 2001

As long as cars are driven by humans, drivers must make appropriate recognition, judgment, and operation to maintain traffic safety. However, when serious errors occur in procedure, traffic accidents result. Figure 7 shows the breakdown of driver error by type of car accident. Generally speaking, miss-recognition is the largest contributing factor in all types of accident, miss-operation and miss-judgement are more significant in single car accidents and head-on collisions.

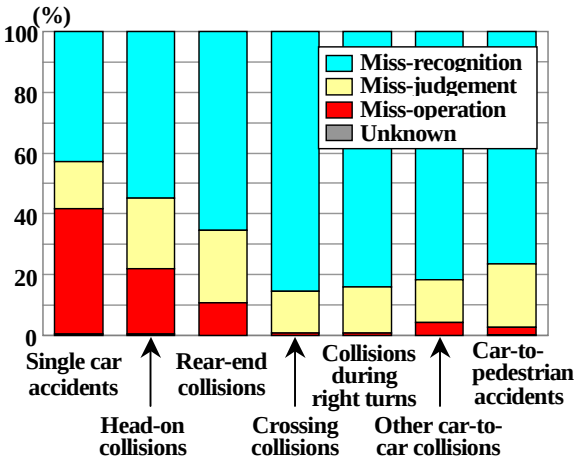


Figure 7. Driver error by Type of Car Accident in Japan in 2001

Most single car accidents and head-on collisions begin when one car leaves its lane. VSC helps the driver maintain the intended path of the vehicle (see Figure 4). VSC, therefore, is considered to be one of the effective devices in reducing serious accidents.

Previous Research

There has been much research to try to confirm the effectiveness of VSC or ESP.

We confirmed the effectiveness of VSC by comparing the behavior of vehicles with and without VSC, driven by 40 ordinary drivers in certain conditions [6]. The results showed that no vehicles with VSC span off the course, while 45% of the vehicles without VSC ran off the tracking during a slippery curve test.

Langwieder examined approximately 1600 car-to-car and single car accidents involving serious passenger injury and approximately 950 car accidents involving young drivers in Germany [7]. He showed that about 25% of all the accidents accompanied skidding and pointed out that there was a critical path which ranged between 40 and 70 meters in approximately two-thirds of all cases. He consequently reached a conclusion that a dynamic electronic brake system such as ESP would provide valuable assistance for the driver in stabilizing the vehicle and would clearly reduce the number of accidents involving skidding.

Zobel made use of the Hanover Medical University (MHH) database and showed by simulation that ESP may assist the driver to avoid leaving the road, using an accident example as a case study [8]. He analytically examined the database and pointed out a large number of persons were injured in skidding-related accidents on dry roads. He suggested that with regard to all critically injured persons (MAIS 5+), the proportion of skidding-related accidents is much higher, so ESP can be expected to be highly effective if the driver accepts the assistance offered by ESP with due caution.

Sferco made use of The European Accident Causation Survey (EACS) data and found that there were 389 vehicles in loss of control fatal accidents out of 1093 fatal accidents, 460 vehicles in loss of control injury accidents out of 1851 injury accidents [9]. He reached the conclusion that EACS data suggests ESP would have a probable or definite influence in about 67% of fatal accidents involving loss of vehicle control and 42% of the corresponding injury accidents.

DaimlerChrysler (DC) announced in a press release in November 2002 that, by analyzing 1.5 million pieces of sampled accident data from 1998 to 2001, accumulated by the Federal Statistical Office in Germany, they found that comparing 2000/2001 DC-cars with ESP and 1999/2000 cars without ESP, the accident rate for cars with ESP was 15% lower. The result showed 4% fewer DC cars with ESP involved in single car accidents, dropping from around 14.4 and 15% to 10.6 or 10.7%.

While, these results show the expected real-world effect of VSC or ESP, they are actual results only for DC. In the following section, the effectiveness in the real-world of installing VSC in vehicles will be shown.

Analysis Methodology

Accident rates for vehicles vary depending on whether they are driven by young or elderly drivers. So to make an accurate comparison, one must compare conditions where the characteristics of the vehicles and the ages of the drivers do not vary a great deal. 3 TOYOTA passenger cars popular in Japan were selected in which VSC had been installed between model changes.

In comparing the accident rates, we set the registered period and the investigation period as shown in Figure 8. The investigation period of accidents was limited to the first 5 calendar years of the vehicle's life including the registered year, so as to cancel out the influence of vehicles' age as much as possible. That is, the investigation period was set from 1994 to 1998 for the vehicles registered in 1994, from 1995 to 1999 for the vehicles registered in 1995, and so on.

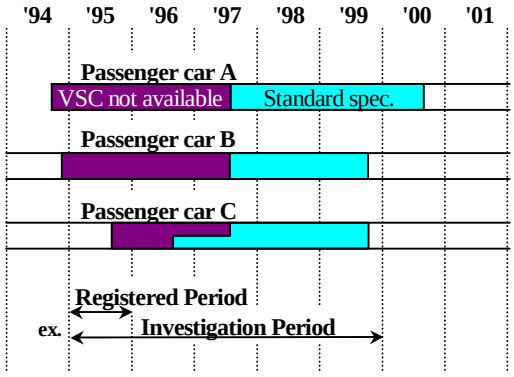


Figure 8. Registered Period of Vehicles with and without VSC, of the Same Model

As the investigation periods do not fully coincide, we must consider whether trends of traffic accidents changed or not. Figure 9 indicates that rear-end collisions and crossing collisions have increased in the last several years, while single car accidents and head-on collisions have changed little.

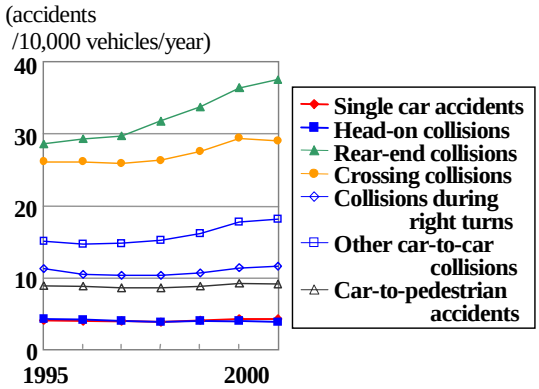


Figure 9. Trend of Accident rate caused by Cars

In addition, the number of vehicles that left the market should be considered. Figure 10 shows the rate of cars still in use, estimated from the statistics of cars in use in Japan, reported by the Automobile Inspection & Registration Association (AIRA). The reason why stair-looking points exist in the 3rd and the 5th years is that owners are obliged to carry out vehicle inspections in these years, and some owners choose to change their cars at these points. We took the estimated rate of the cars still in use into consideration in calculating each accident rate.

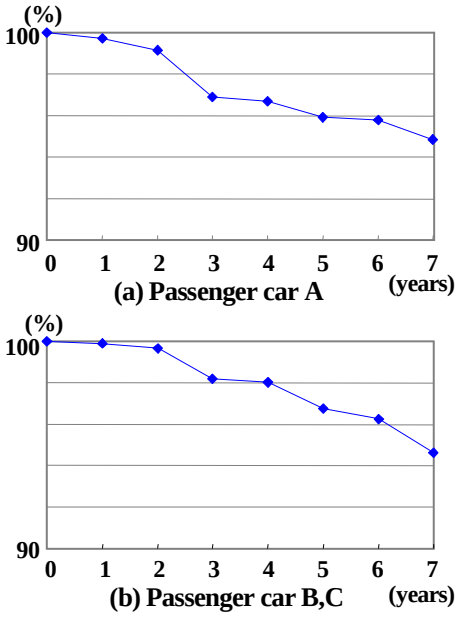
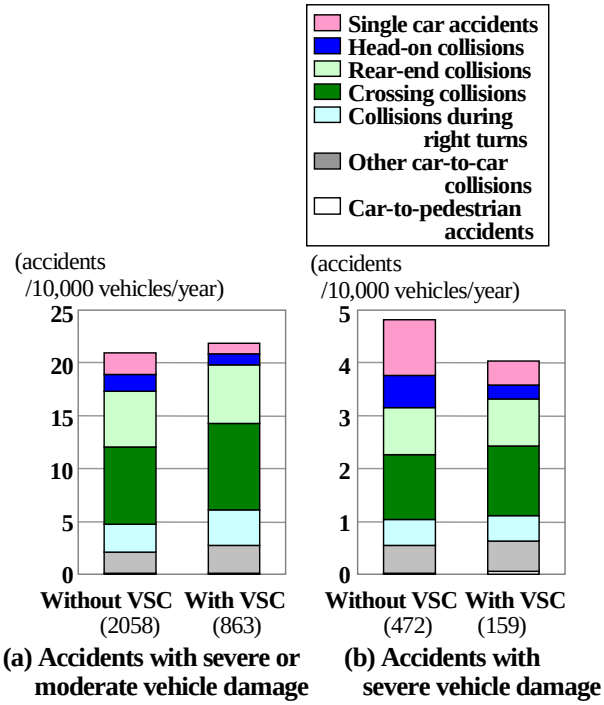


Figure 10. Cars still in Use from the First Registration

RESULTS

We counted approximately 980,000 vehicle-years without VSC and approximately 390,000 vehicle-years with VSC. These figures were used to calculate accident rates and casualty rates.

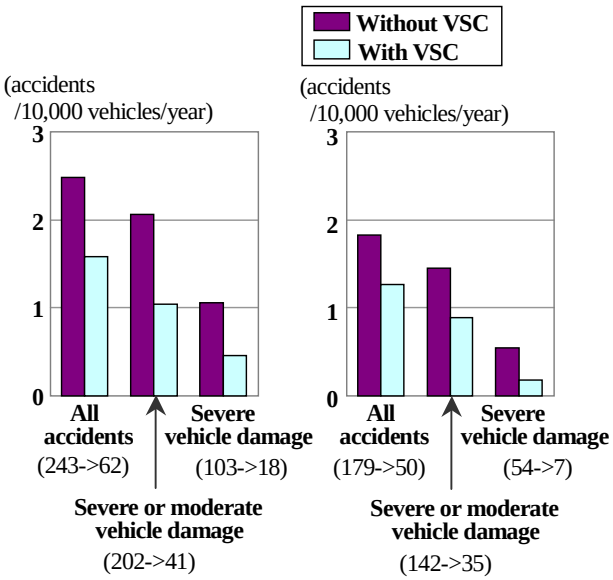
Accident rates examined by extent of vehicle damage are shown in Figure 11. It can be seen that the rates for single car accidents and head-on collisions decreased while they did not decrease in Figure 9. It is thus thought that VSC may decrease the number of single car accidents and head-on collisions, just as we expected. These 2 types of accidents were further studied.



(a) Accidents with severe or moderate vehicle damage **(b) Accidents with severe vehicle damage**

Figure 11. Accident rates Caused by Passenger cars A, B & C by Extent of Vehicle Damage

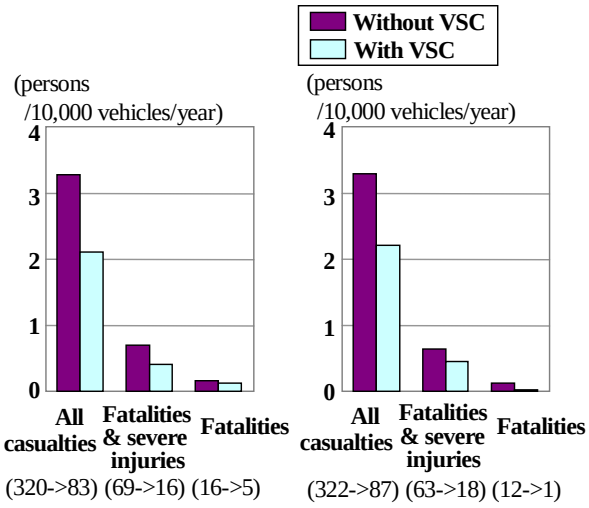
When the results are examined by the extent of vehicle damage, as illustrated in Figure 12, the reduction of the accident rate is approximately 35% for single car accidents and 30% for head-on collisions with other automobiles, and are approximately 50% and 40% reductions for accidents where severe or moderate damage occurred. These results indicate that the more severe the crash, the more effective VSC may be. In these results, cyclists, including motor cyclists, and agricultural vehicles are excluded from the data of the head-on collisions because these vehicles are disproportional to other vehicles when discussing the extent of vehicle damage. They are also excluded in the next Figure 13.



(a) Single car Accidents **(b) Head-on Collisions with Other Automobiles**

Figure 12. Reduction of Accident rate by Extent of Vehicle Damage

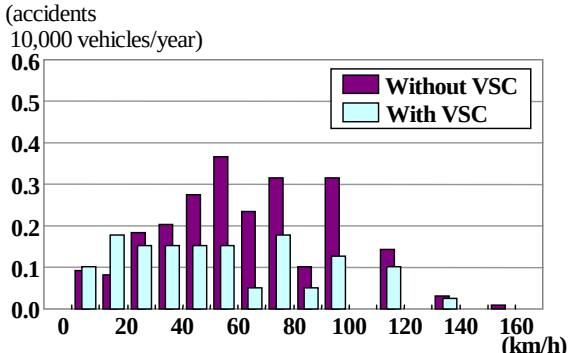
When the results are examined by the extent of injury as illustrated in Figure 13, the reduction in the casualty rate is approximately 35% in both single car accidents and head-on collisions with other automobiles. We had so few fatalities and severe injuries that the reduction ratio could not be estimated for them.



(a) Single car Accidents **(b) Head-on Collisions with Other Automobiles**

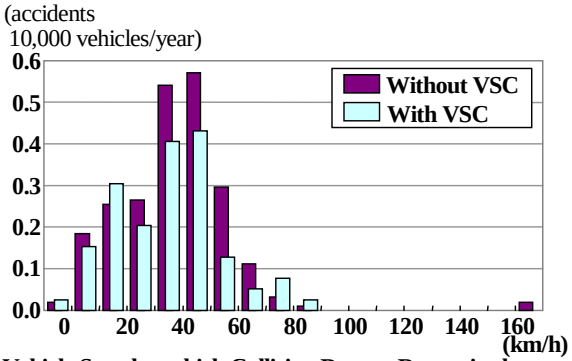
Figure 13. Reduction of Casualty rate by Extent of Injury

Next, the distribution of the speed at which collision danger is recognized by the driver of passenger cars A, B and C is examined, as illustrated in Figure 14. It can be seen that for vehicles with VSC, the number of accidents that occurred in the higher speed range was reduced. VSC may be more effective in this range. It may therefore be considered that this is one of the reasons why more severe crashes were reduced by VSC.



Vehicle Speed at which Collision Danger Recognized

(a) Single car Accidents



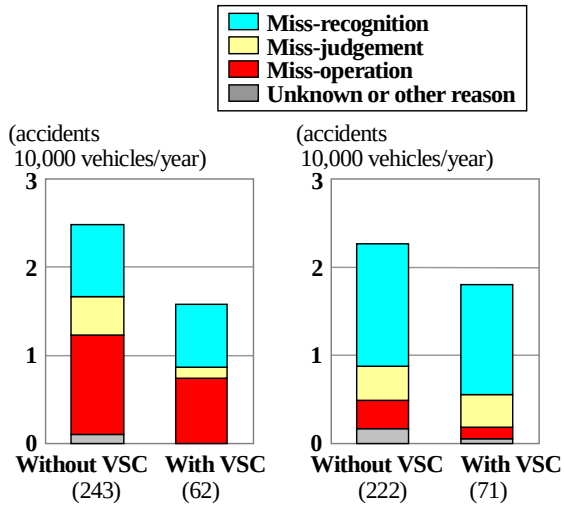
Vehicle Speed at which Collision Danger Recognized

(b) Head-on Collisions with Other Vehicles

Figure 14. Reduction of Accident rate by Speed

Statistics offer little explanation why the accident rate looks reduced, but Figure 15 presents some suggestions. It indicates that VSC helps little to reduce accidents resulting from miss-recognition, but helps to some extent to reduce accidents resulting from miss-operation or miss-judgement in these types of accidents.

It however should be noticed that VSC cannot compensate for driver errors every time, because it works only when the driver makes the correct maneuver before the crash.



(a) Single car Accidents

(b) Head-on Collisions with Other Vehicles

Figure 15. Reduction of Accident rate by Driver Error

On the other hand, for other types of accidents, such as crossing collisions or rear-end collisions, there seems to be no effect on the difference in accident rates between vehicles with VSC and those without (see Figure 11). This is thought to be due to the fact that in these types of accidents, there are few cases that exceed the limit of vehicle dynamics performance, which is where VSC comes into play.

CONCLUSION

From analysis of the statistics of traffic accidents in Japan with and without VSC using 3 TOYOTA passenger cars, it can be concluded that,

1. (1) It is estimated that the accident rate of the vehicles with VSC showed approximately a 35% reduction for single car accidents, a 30% reduction for head-on collisions with other automobiles, and approximately 50% and 40% reductions for accidents where severe or moderate damage occurred, compared to that of the vehicles without VSC.
   (2) It is estimated that the casualty rate of vehicles with VSC showed approximately a 35% reduction for both single car accidents and head-on collisions with other automobiles.
2. VSC may be considered to help reduce accidents resulting from a driver's miss-operation and miss-judgement in these 2 types of accident to some extent. But it is needless to say that VSC isn't an all-powerful device to compensate for all driver

3. It could be considered that one reason that these types of accidents, especially the more severe ones, are reduced is that VSC may be able to reduce accidents in the higher speed range where vehicle dynamics performance plays a greater part.

FUTURE ANALYSIS FOR ACTIVE SAFETY

Our research revealed that VSC is effective in reducing single car accidents and head-on collisions to some extent. However, it is still uncertain what maneuvers it is able to control in actual traffic. It is necessary in the future to examine all types of safety equipment, not just VSC, in order to understand how they have worked or not worked, to improve the ability of the devices.
For this purpose, it is necessary that all accident data contains more detailed information regarding the devices the vehicles are equipped with, and their maneuvers before crashes. At the same time, this kind of research should be performed in other countries to promote consumers' understanding of the value of safety devices and to promote their greater use.

ACKNOWLEDGEMENTS

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